"Apparatus and method for processing of plant material"

Field of the Invention

The present invention relates to improvements in or relating to the processing of bast crops or any crop containing an inner core surrounded by an outer fibrous layer. Examples of such crops include, but are not limited to, *Cannabis sativa*, better known as hemp, Kenaf, Ramie, sugar cane, nettles, Jute, Sesbania or Sisal.

Background of the Invention

Bast crops contain an inner core, sometimes called a hurd, surrounded by an outer fibrous layer. One such bast crop is hemp. Hemp has a number of commercial uses due to the properties of its fibre, which include strength and resilience. The fibre, which can be extracted from the outer fibrous layer of a hemp stalk has a variety of uses and may be a constituent in the production of paper, fibreboard and rope. Hemp fibre also has the capacity to replace cotton as a component of textiles. With the likelihood of gradual relaxation of strict legislative controls over cultivation and processing, hemp is likely to become increasingly attractive to farmers as a valuable cash crop.

The stalk of a hemp plant is generally of substantially circular cross-section, having a fibrous outer layer (skin or bast) and an inner core or hurd. The fibre of the plant is generally the more valuable commodity, although the hurd has some uses. It is therefore desirable to separate the fibre from the hurd to yield a value-added commodity.

The principal difficulty in processing hemp has been found to lie in separating the fibre from the hurd. This process is referred to herein as decortication.

A number of proposals have been suggested for separating the fibre from the hurd. The principal category of decortication is mechanical separation. Of the mechanical operations, traditionally scutching has been the most widely used. Scutching involves manually beating the hemp stalk until the hurd is dislodged from the fibre. This is usually followed by a manual mechanical stripping operation using a bladed scutching wheel to strip the outer fibre away from the hurd. As this method of decortication is generally a manual operation, it can be very labour-intensive and time-consuming and hence inefficient. Scutching has therefore not been found suitable for large scale commercial processing of hemp.

Other mechanical decortication methods include the use of ultrasonics, which employ sound waves to generate vibrations to break the bonds between fibre and hurd.

Processing of hemp in a similar manner to that of flax has also been proposed. This method involves retting the hemp, drying and breaking the solidified hurd until the fibre separates from the core. Again this method is time consuming and not generally suited to large-scale commercial operation. There have also been several attempts to develop a method for decortication by processing freshly cut hemp stalks which method bypasses the need for time consuming treatment prior to separating hurd from the fibre. Patent specification GB 1235387 is directed to the processing of green hemp where each plant stalk is passed through rollers, the stalk is split and beaten before the hurd is removed while the stalk is passed between two conveyors. A disadvantage of this method is that uncleaned stalks remain after the process. Specification GB 2205865 treats plant stalks as soon as they are cut, however the hurd is removed from the stalk by crushing the stalks between cylinders. Specifications GB 693833 and US 5465464 describe methods of processing which, while not requiring time consuming pretreatment of the raw material, are not directed towards the processing of green or freshly cut plant stalks, particularly green hemp stalks.

None of such prior art methods is suited to broadacre production involving both the harvesting of the hemp crop and efficiently separating the bast from the hurd of the harvested stalk on a commercial scale.

Patent specification WO 97/45573, the disclosure of which is incorporated herein by reference, describes a method and apparatus for processing the green plant stalk of a bast crop. To encourage the separation of the hurd from the fibre, the bonds between the fibre and the hurd are ruptured. The stalk is subsequently split and the exposed hurd is stripped from the fibre by the abrasion of a toothed roller on the hurd. Bond rupturing is effected by passing the green stalks between a complex series of counter-rotating pressing rollers, before the stalk is split and stripped of the hurd. This proposal is somewhat complex and requires significant power to drive the rollers.

The present invention provides an effective alternative to the foregoing proposals for the processing of a bast crop, and in particular, green or non-retted bast crops.

Summary of the Invention

In a first aspect, the present invention provides a method for processing plant stalk having a fibrous outer part (skin) and an inner hurd, the method including the steps of:

striking the stalk at at least one location along the stalk length so as to cause the stalk to bend at the at least one location thereby causing fracture of the hurd across the stalk at each striking location so as to expose at least part of the inner hurd; and

separating at least part of the hurd from the skin.

Preferably at least part of the skin is also caused to split on contact with the striking means and therefore, upon striking, at least part of the hurd fractures across the stalk and the skin splits longitudinally at least at the location at which the stalk has been struck.

In a further aspect, the present invention provides a method for processing at least one plant stalk having a fibrous outer part (skin) and an inner hurd, the method comprising the steps of:

feeding the stalk(s) to a bending element;

striking the stalk with striking means to cause the stalk(s) to bend over the bending element to fracture the hurd across the stalk and to split the skin longitudinally of the stalk, and

separating at least part of inner hurd from the skin.

The bending element may be an edge, preferably a blunt or small radius edge. The bending element is preferably a plate, or forms part of a plate, or the like, although it may be of any shape provided it has an edge over which the stalk may be bent.

The striking means may be in the form of a plate, blade or the like.

Preferably the at least one stalk is/are subjected to a primary strike so as to bend the stalk around the bending element a thereby fracture the hurd across the stalk and optionally split the skin longitudinally and then to a subsequent secondary strike so as cause splitting or further splitting of the skin and to separation of fractured fragments of the hurd from the skin.

In one preferred form of the invention, the primary strike is followed substantially immediately by the secondary strike. This may be achieved by use of striking means comprising a first striking element that performs a first strike and an associated second striking element that performs a second strike immediately thereafter. The end of the second striking element may extend beyond the end of the first striking element. The striking end of the first element may be located from the bending element by about the width of the stalk, for example, by about 10-15mm, so that it can bend the stalk over the bending element so as to fracture the hurd across the stalk and preferably split the skin longitudinally of the stalk. The striking end of the second element may be spaced from the bending element by about the thickness of the skin, for example, about 0.2mm to about 2.0mm. The second element promotes

longitudinal splitting of the skin and may also "scoop" out the hurd fragment from the skin. The first and second elements of the striking means may be formed separately or they may be formed as a monolithic element, for example, by moulding.

The plant stalk may be struck by a plurality of striking means such that as each stalk is fed to the bending element, substantially contiguous portions of each stalk are subjected to the fracture and/or splitting followed by removal of the skin.

The plurality of striking means may be sequentially delivered to the bending element by means of a conveyor or the like so that the free end of each striking means strikes a portion of the stalk. Alternatively, the striking means may be associated with a rotor, with the striking means forming the, or part of, the vanes of a vaned-rotor.

The stalk may be fed to the bending element by feeder means. The feeder means may be a pair of rollers through which the stalk is drawn.

The stalk may be "green", dry, semi-dry, retted or non-retted.

The method according to the present invention may include the additional step of observing the growth pattern of the hemp plant in the field, whereupon harvesting and decortication of the crop may be commenced at a predetermined phase of growth of the plant.

It has been observed that the strength of the bond between the fibre and hurd varies at various stages of growth of the plant. In a preferred embodiment, harvesting and decortication are commenced when the plant is green, also known as freshly cut or fresh green. The fibre of the stalk preferably remains sufficiently fine for textile use, that is to say, prior to pollen formation. The hemp plant stalk may be harvested by cutting and stripped of leaves using known methods. The hemp may be harvested at 50 to 80 days maturity and preferably before lignins form. Preferably the hemp is harvested before the outer fibre thickens and most preferably before the outer fibre forms bundles. Before the adhesives between the hurd and outer fibres harden and most preferably at approximately 60 days maturity or just prior to flowering are particularly preferred indicators of a suitable time to harvest a large crop for use in accordance with the present invention. The cut end of the plant stalk is referred to herein as the butt end.

For best results processing of the stalk is preferably commenced before the "adhesive" between the fibrous outer layer and the inner core dries. Normally this is within two hours of harvesting but preferably immediately after harvesting. Most preferably processing commences not more than 15 minutes after harvesting. Commencement of processing within two minutes of harvesting is particularly preferred.

In another aspect, the present invention provides an apparatus for processing stalk having a fibrous outer part and an inner hurd comprising:

a feeder for feeding the stalks for processing;

a decorticator for decorticating the fed stalks comprising:

a bending element to which the stalks are fed at a predetermined speed; and

one or more striking means that cause each stalk to bend over the bending element and to thereby fracture the hurd across the stalk and/or longitudinally split the skin at various locations along the stalk length, wherein the striking means further serves to separate the hurd from the fibrous outer part of the stalk.

The bending element may be an edge, preferably a blunt edge. The bending element may be a plate, or form part of a plate, or the like. The bending element may be in the form of a hump.

The means for feeding the stalks into the decorticator may be manually operated or it may be automated. Preferably the feeding means is/are one or more pairs of feeder rollers through which stalks are fed and guided for entry into the decorticator. The feeder rollers may include a cylindrical surface that is textured so as to achieve sufficient grip of the stalks. Preferably the texturing is provided by a series of projections extending along the roller length. When feeder rollers are employed, sufficient grip of the stalks by the feeder rollers is necessary, as the primary purpose of the feeder rollers is to control the rate at which the stalk material enters the decorticator. In this regard, as the rotor rotates at a much greater speed compared to the rate at which the stalks are fed into the decorticator, it is possible that without proper feed control, the stalks will be forced through the decorticator at the rate of the rotor; this would be highly inefficient and undesirable. The feeder rollers, in addition to a flattener which is further described below, may also serve to compress, and hence condition (i.e., soften, crack etc.) the stalk fibrous outer part prior to entry into the decorticator, particularly when the bast crop is green.

As mentioned above, the plurality of striking means may be delivered to the fibre adjacent the bending element by means of a conveyor or the like. The conveyer may travel transversely to the direction of movement of the stalk(s) fed to the bending element with the striking means extending approximately perpendicularly to the conveyor.

In a preferred form of the apparatus of the invention, the plurality of striking means is supported on a rotor such that the striking means are "vanes" that can be rotated .

Preferably the vanes on the rotor, the bending element and feeder rollers co-operate and are adjustable so as to achieve optimal decortication. The position of the vaned-rotor may be fixed while the position of the bending element and feeder rollers is adjustable in relation to the vaned-rotor. It will be clear to the skilled reader that it is the relative positioning of these elements that is important and so the vaned-rotor may be adjustable whilst the feeder rollers/bending element may be fixed.

As already indicated above, each striking means may comprise a first striking element that performs a first strike and an associated second striking element that performs a second strike immediately thereafter. The end of the second striking element may extend beyond the end of the first striking element so as to form a recessed portion at the end of the striking means.

The first and second elements of the striking means may be formed separately or formed as a monolithic means, for example, by moulding. The second striking element may be adjustable so that its radial length may be increased or decreased to suit the thickness of the particular type of stalks being processed.

Where, for example, the striking means is a vane on a vaned rotor, the second striking element may be a blade or the like attached to a respective vane. The blades radial position may be adjustable.

The speed of the striking means (for example, a vaned-rotor) may be adjusted and the alignment of the bending element in relation to the vaned-rotor may also be adjusted so at to obtain the optimum distance between the bending element and the stalk striking point of the vanes. The exact configuration and alignment of the rotor vanes and also the vaned-rotor in relation to the feeder rollers and bending element depends on the type and condition of the plant material to be processed and may be easily determined by the skilled person by trial and error. In a particularly preferred embodiment of hemp processing, the components of the decorticator are aligned so as to achieve flexing and striking (and therefore fracture and/or splitting), at, specifically, various transverse fibrous reinforcements that occur naturally along the length of the hemp stalk. This results in a more efficient fracture/splitting action and therefore, more efficient separation of the fibrous outer layer from the inner hurd.

Preferably, striking portion of the rotor vane(s), blade(s) (if present), or both, are sufficiently "sharp" so as to cause longitudinal splitting of the stalk skin on contact. For example, the striking portion may be an edge of the vane and/or blade. Most preferably, the stalk is split on contact with the first rotor vane while contact of the stalk with the second rotor vane and/or plate results in the separation of the fractured and/or split stalk from the inner hurd. Preferably also, the fibrous outer part is

immediately separated from the hurd after fracture and/or splitting by the use of blades that are co-attached and configured in such a way so as to achieve immediate fracture and/or splitting/separating action, as will be further described below.

The vaned-rotor may rotate at a much greater speed compared to the speed of the feeder rollers (and hence the entry speed of the stalk into the decorticator). The rotational speed of the vaned-rotor depends on the speed at which the stalk is fed to the bending element. If the segments between strikes is too long, long unsplit sections remain between fractures, resulting in inefficient removal of hurd. The rotor speed is variable against the speed of the infeed on the basis of, at least, the type of crop, the age of the crop and the average stem thickness and length. Other bast crops may need a different speed relationship between rotor and infeed rollers. The speed depends upon the surface speed of the roller attaining the ideal harvest speed. The roller itself can be any radius from quite small (faster revs) to quite large (slower revs). For example, the vaned-rotor may rotate at between about 2,000 to 4,000 or more rpm, depending the physical characteristics of the stalk.

The apparatus of the present invention may further include a means for providing an air flow, the air flow being such as to entrain at least part of the separated hurd and transporting the separated hurd through the at least partially open side of the air flow means to remove the separated hurd.

In the case of a vaned-rotor, the vanes themselves induce airflow. This airflow may be augmented by the use of additional non-striking vanes.

Preferably the means for providing air flow are able to induce high velocity air flow. The means for providing air flow may be one or more jets and/or ducts or the like associated with, or capable of being associated with, a source of air. The means for providing air flow may be one or more gaps between components of the device. The means for providing air flow may be, for example, via the thread guard gap. This has the advantage of preventing loose fibres, plant liquids and particles from entering the gap of the thread guard. Preferably, the vaned rotor has apertures therethrough to permit the high velocity air to pass through the rotor and thereby eject any hurd.

The air jets may carry water droplets, mist or vapour to increase the air-flow effect and/or control the moisture content. Enzymes may be introduced with this to start the degumming process. Release agent such as hemp oil or linseed oil may be added to the air to avoid sticking of the stalk component to parts of the decorticator.

The source of air to the means for providing airflow may form part of the apparatus of the present invention or it may be separate, in which case the apparatus of

the invention may include means for connection to such a source of air. The source of air may be an air blower, compressor or the like.

The apparatus in accordance with the invention may also comprise a slatted conveyor which serves to transport the separated hurd and skin fractions from the apparatus; that is, the separated hurd may fall through a slatted conveyor into a collection bag while the separated fibrous outer part may be conveyed by the conveyor to a separate collection bag located at the end of the conveyor. Preferably, the air flow from, for example, the vanes of the rotor, also assists in forcing the hurd segments downwards through the slats of the slatted conveyor, whereas the fibre is conveyed on the conveyor. The separated hurd and fibrous outer fractions are then able to be separately collected for further processing.

The apparatus of the invention may be associated with other components for pre-processing the fibre for entry into the apparatus, for example, a primary stripping stage to strip leaves and/or braches from the stalk. The apparatus of the invention may be associated with means for further processing of the fibre produced by the apparatus, for example chemical treatment means.

The apparatus of the invention is suitable for use as a single component in a fibre processing arrangement or a plurality of apparatuses in accordance with the invention may be incorporated into a processing system for parallel processing of the plurality of stalks.

The apparatus may further include a vacuum extraction arrangement for extraction of the hurd after it leaves the decorticator.

A particular problem associated with the processing of the bast fibre plants is that the bast fibre wraps around the striking means (for example, the rotor vanes). In a preferred form, the apparatus of the present invention provides a solution to this problem by including in the apparatus one or more guard means to prevent fibre wrapping around the rotor vanes. Preferably the guard means is/are one or more thread guard plates.

Depending on the size of the apparatus, the vaned-rotor may be powered from a harvester for example, or alternatively, be self-powered by a petrol engine for example. Preferably, the feeder rollers are powered by one or more separate drive motors. Preferably also, the apparatus comprises some type of bag-system at one or more output ends, which serves to collect the processed and separated hurd and fibre fractions.

In yet another aspect, the present invention provides fibre produced from the application of the method and/or the apparatus provided by the present invention and in

yet another aspect, hurd produced from the application of the method and/or the apparatus provided by the present invention.

The fibre may be subjected to an enzymic treatment as described in PCT/AU02/00931, the disclosure of which is included herein by cross-reference.

A plant stalk to be processed according to processing methods and apparatus of the present invention may be a hemp stalk. A particularly preferred hemp is that of *Cannabis Sativa L.* and species thereof. Other plant stalks envisaged form processing in accordance with the present invention, include Kenaf, Ramie, sugar cane, nettles and other bast crops such as Jute, Sesbania or Sisal.

The particularly preferred embodiment of the invention will now be described in further detail with reference to the following non-limiting example and the accompanying figures.

Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

Brief Description of the Figures

Figure 1 is a schematic view of the apparatus in accordance with one preferred embodiment of the present invention.

Figure 2 is an exploded view of the decorticating section of the apparatus of Figure 1.

Figures 3 to 5 depict the progressive action of the rotor vanes on stalk.

Example

Figures 1 and 2 illustrate one preferred embodiment of the present invention. Referring to Figure 1, the apparatus **1** includes feeder rollers **2** and corresponding drive motors **3** and **4**. Also shown is a petrol motor **5** that powers a vaned-rotor **6**. Hemp stalk or any other bast stalk is fed into the feeder rollers **2**. The stalks may be manually fed into the feeder rollers **2** or may be fed by mechanical means (not shown). Each stalk enters the decorticator section , (shown in more detail in Figure 2), which separates the

fibrous outer part of the stalk from the inner hurd. The separated inner hurd falls through a slatted conveyor **7** into a collection bag (not shown) while the separated fibrous outer part is conveyed by conveyor **7** to a separate collection bag located at the end of the conveyor (not shown).

Figure 2 depicts an open decorticating section of the apparatus wherein only one side plate **8** is shown. A front plate **9** contains two apertures **10** and **11** through which the shafts of feeder rollers **2** pass. The position of the feeder rollers may be adjustable. A corresponding front plate (not shown) is assembled at the other end of feeder rollers **2**. The front plate **9** has elongated slots **30** through which threaded bolts **32** pass for fixing front plate **9** to the side plate. Slots **30** allow for longitudinal adjustment of the distance between the feeder rollers and a vaned roller **14**.

A plate (hump) **12** is attached to the adjustable front plate **9**. The hump **12** may be height adjustable. Stalk **19** is fed to the hump **12** by feeder rollers **2** at a predetermined speed. The speed at which the feeder rollers feed the stalk to the hump depends on the speed at which the stalk is fed to the feeder rollers. For example, if stalks are manually fed, the feeder rollers my rotate at a speed that allows an operator to efficiently feed the stalks to the feeder rollers. Faster feeding may be achieved by mechanical feed means to the feeder rollers and the rotational speed of the feeder rollers is adjusted accordingly. In this particular embodiment, the vaned-rotor rotates at around 1800-2000 rpm, but the ideal is that speed which is sufficient to match input roller speeds which are sufficient to allow a harvester in which the decorticator device is mounted to travel at around 5 km per hour so a 2 metre wide harvester /decorticator can do 1 hectare in one hour at least. The rotor speed is variable against the speed of the infeed on the basis of, at least, the type of crop, the age of the crop and average stem thickness and length. Other bast crops may need a different speed relationship between rotor and infeed rollers. As already mentioned above, the speed really depends upon the surface speed of the roller attaining the ideal harvest speed. The roller itself can be any radius from quite small (faster revs) to quite large (slower revs.)

Stalk fed to the hump by the feeder rollers is caused to abruptly change direction by bending over the hump upon action of one of the rotating vanes **13** of a vaned-rotor **14**. This results in fracture of the hurd at the location of impact. Immediately behind the front plate **9** is a thread guard **16** (see Figure 2), which serves to minimise any entanglement of the separated hurd fraction in the rotor vanes **13**. Also minimising the adherence of the separated material in the rotor vanes **13** is a scraper **17** located on a small plate **18** positioned immediately behind the thread guard **16**. Preferably the thread guard **16** and vaned-rotor **14** are fixed whereas the feeder rollers **2**, the front

plate **9** and hump **12** are all adjustable so as to achieve optimal striking and therefore inner hurd/fibrous outer part separation.

Each vane **13a** of the vaned rotor is associated with a blade **13b** wherein the blade extends radially to a greater extent than the vane to form a "scoop" **37**. In this particular embodiment, each vane comprises a blade attached to the vane.

In operation, stalk(s) are continuously fed by the feeder rollers to hump **12**, a first rotating vane **13a** of the vaned-rotor **14** contacts the stalk **19** causing it to bend and split the skin along the stem and the hurd to fracture across the stem. As the vaned-rotor **14** continues to rotate, a blade **13b** subsequently contacts the stalk **19** serving to further fracture and/or split the stalk and also pull out inner hurd **20** as a segment flowing into the maelstrom of air flow that is created by the rotation of the vanes (see Figure 5). The air blast forces the hurd segments downwards through the slats of the slatted conveyor, whereas the fibre is conveyed on the conveyor. The separated inner hurd **20** and fibrous outer part **21** fractions are then separately collected for further processing as shown in Figures 4 and 5.

The apparatus can be made as wide as is practical to fit into a harvester to deal with fresh green stems, harvested at the optimum time for high quality textile fibre or set up in a static mill to process dry material that may be in sheaves or roll-bale form. The latter will tend to make fibre best suited for non-woven products, for example, to replace fibreglass used in composites and other products.

Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is solely for the purpose of providing a context for the present invention. It is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed before the priority date of each claim of this application.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.